

# Validation of the EOS MLS $\text{HNO}_3$ Measurements

Aura Validation Meeting: 21 September 2005

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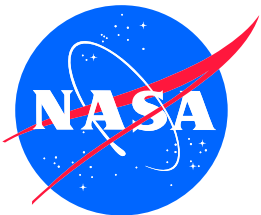
ASUR Team

FIRS & MkIV Teams

ACE Team

Odin/SMR Team

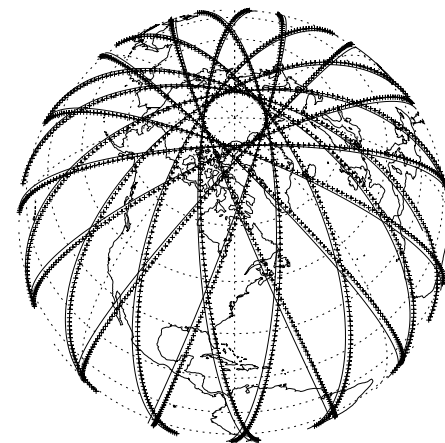
MIPAS Team



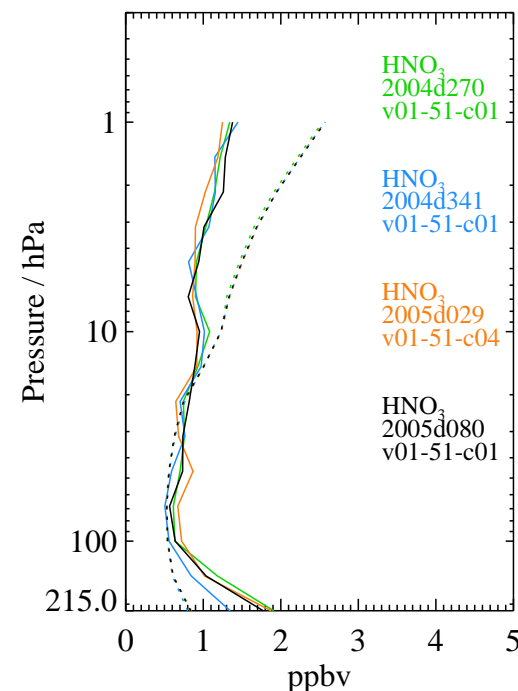
# Overview of the EOS MLS $\text{HNO}_3$ product

- ❖ The standard product for version 1.5  $\text{HNO}_3$  is taken from the 240 GHz retrieval at and below 10 hPa and from the 190 GHz retrieval at and above 6.8 hPa.
- ❖ V1.5  $\text{HNO}_3$  are scientifically useful over the range 147 to 3.2 hPa; averages may prove useful at 215 hPa, but determining their reliability will require further analysis.
- ❖ MLS data are reported at six pressure levels per decade change in pressure ( $\sim 2.5$  km).
- ❖ The true vertical resolution is  $\sim 3.5$  km over the range 147 to 10 hPa, degrading to  $\sim 4.5$  km at 3.2 hPa.
- ❖ Adjacent profiles are separated by  $1.5^\circ$  great circle angle along the orbit track, corresponding to 165 km (24.7 s).
- ❖ Spatial resolution is  $\sim 300$ – $400$  km along-track and  $\sim 10$  km cross-track for the  $\text{HNO}_3$  measurements.
- ❖ Observed scatter in the data, evaluated in a  $20^\circ$ -wide latitude band centered around the equator where atmospheric variability is expected to be small, indicates a measurement precision of  $\sim 1$  ppbv throughout the profile.
- ❖ The estimated single-profile precision reported by the Level 2 software overestimates the observed scatter above  $\sim 10$  hPa.
- ❖ It is recommended that  $\text{HNO}_3$  profiles for which  $\text{QUALITY} < 0.17$  be discarded to eliminate obvious outliers.
- ❖ The  $\text{HNO}_3$  profile is often slightly oscillatory.
- ❖ Clouds in the upper troposphere have no influence on the lower stratospheric  $\text{HNO}_3$  observations.

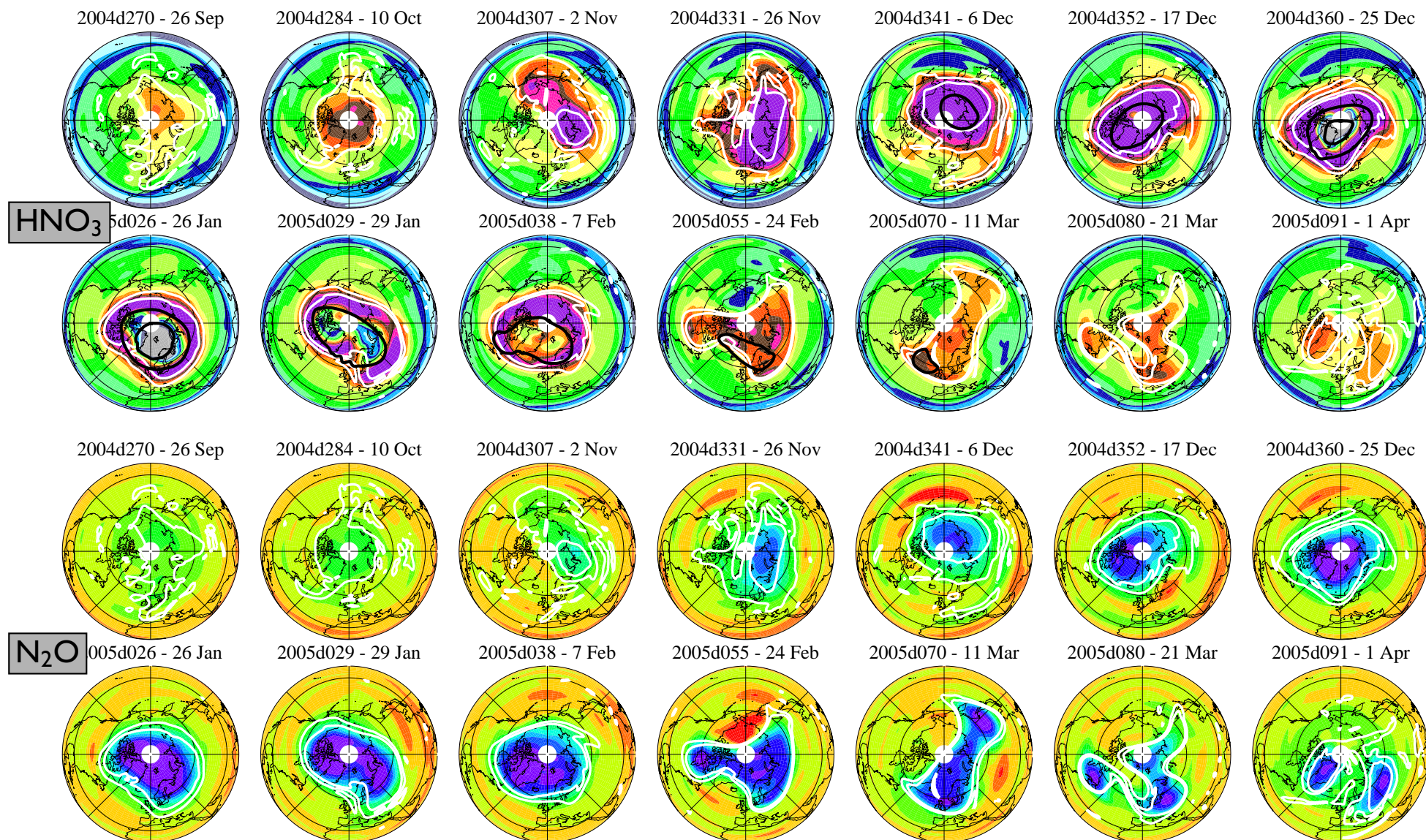
EOS MLS data coverage  
in a 24-hr period



Est Prec vs Obs Scatter



## Sanity check: comparisons with PV and MLS N<sub>2</sub>O for individual days

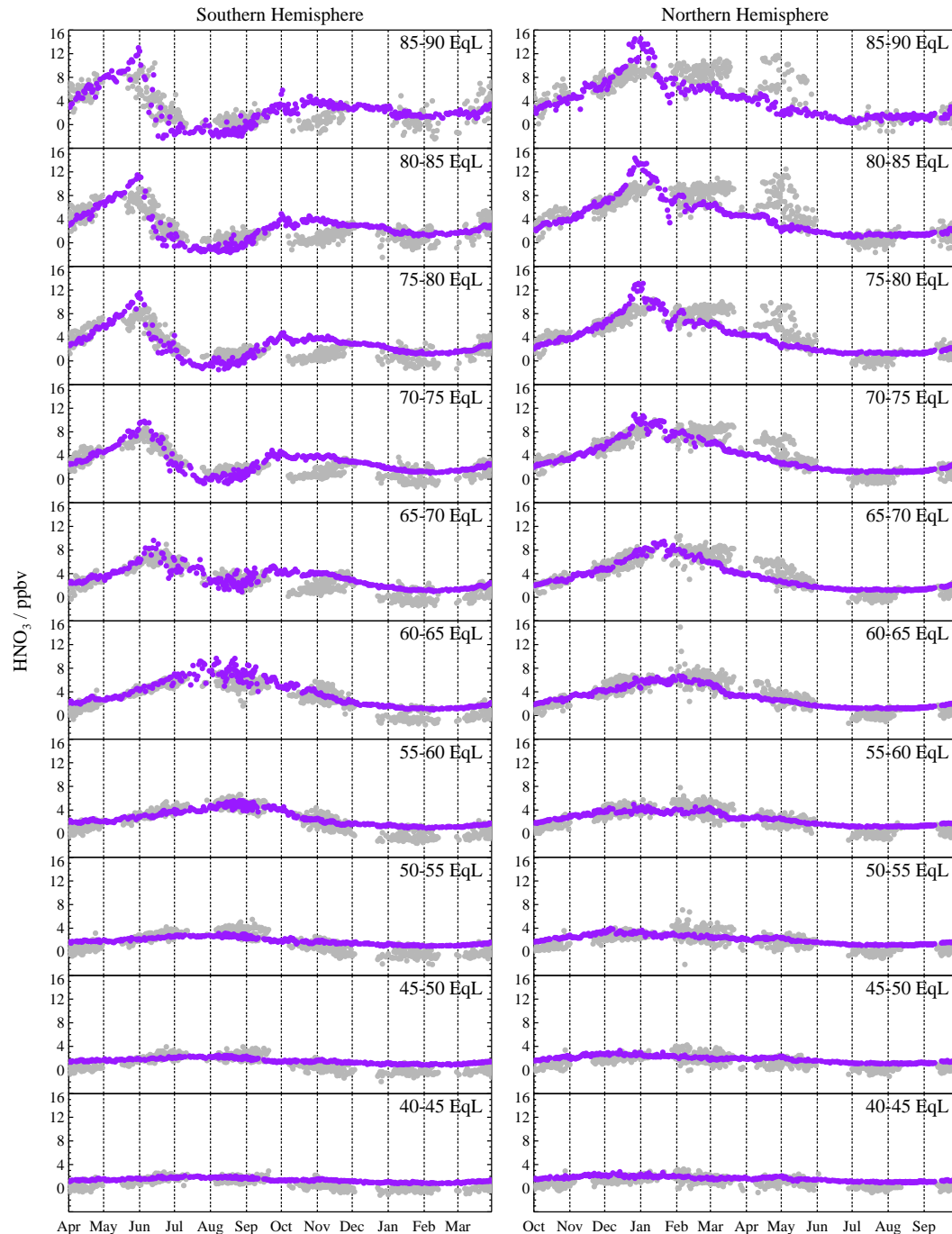


- ❖ The seasonal evolution of HNO<sub>3</sub> in the lower stratosphere conforms to expectations and matches that of GMAO GEOS-4 PV and MLS N<sub>2</sub>O very well.

# Comparison with UARS MLS $\text{HNO}_3$ measurements

Data through 2005d254

410 K

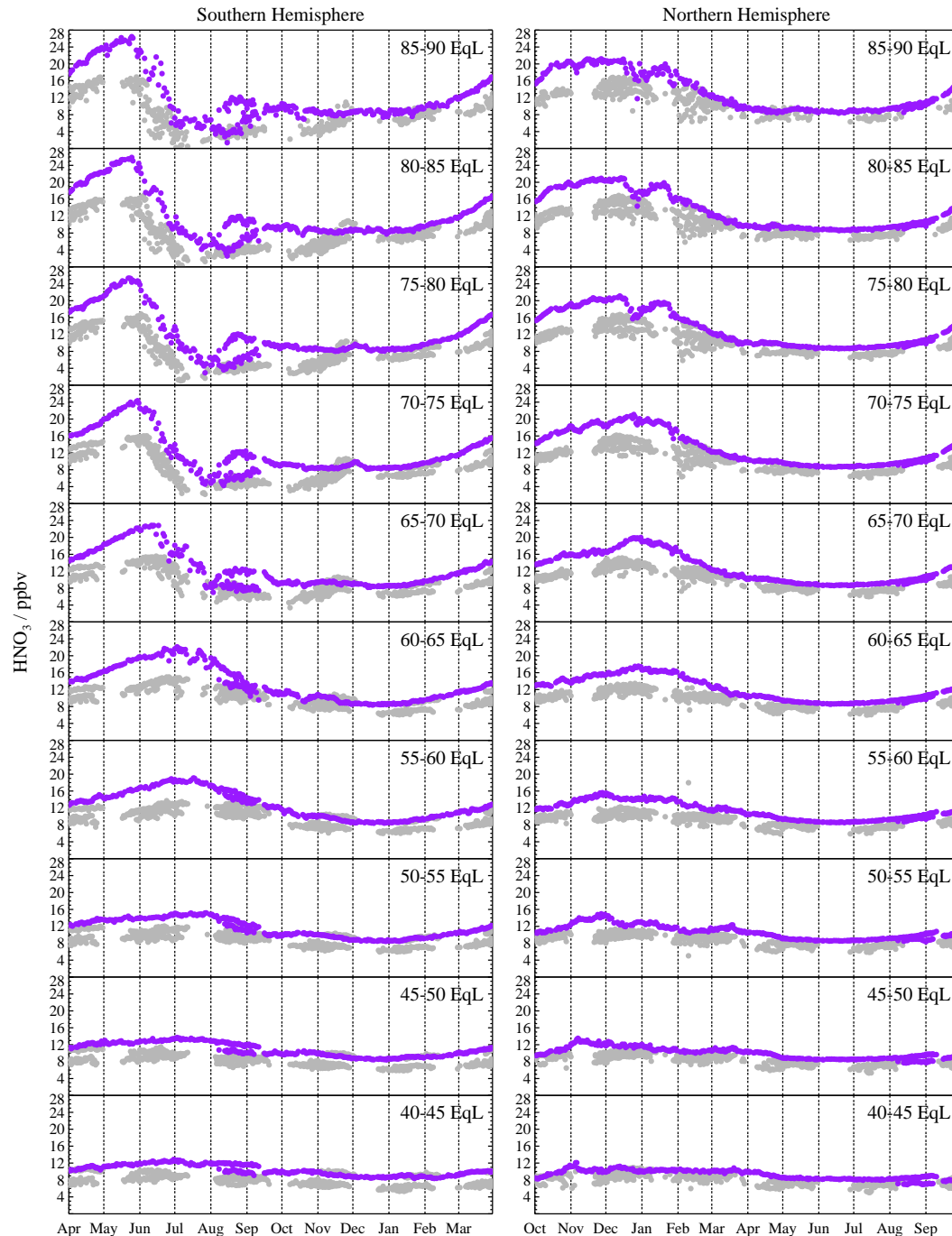


- ❖ This plot shows time series of MLS  $\text{HNO}_3$  at 410 K ( $\sim 100$  hPa, 14 km) for both the Southern (left) and Northern (right) Hemispheres.
- ❖ Grey dots show daily means in  $5^\circ$  equivalent latitude bands from  $40^\circ$  to  $90^\circ$  of data from the MLS instrument on UARS for 9 years (1991–2000).
- ❖ Purple dots show daily averages of EOS MLS  $\text{HNO}_3$  data from mid-August 2004 to mid-September 2005.
- ❖ The evolution of  $\text{HNO}_3$  over an annual cycle, and its latitudinal distribution, generally matches that observed by UARS MLS very well.

# Comparison with UARS MLS $\text{HNO}_3$ measurements

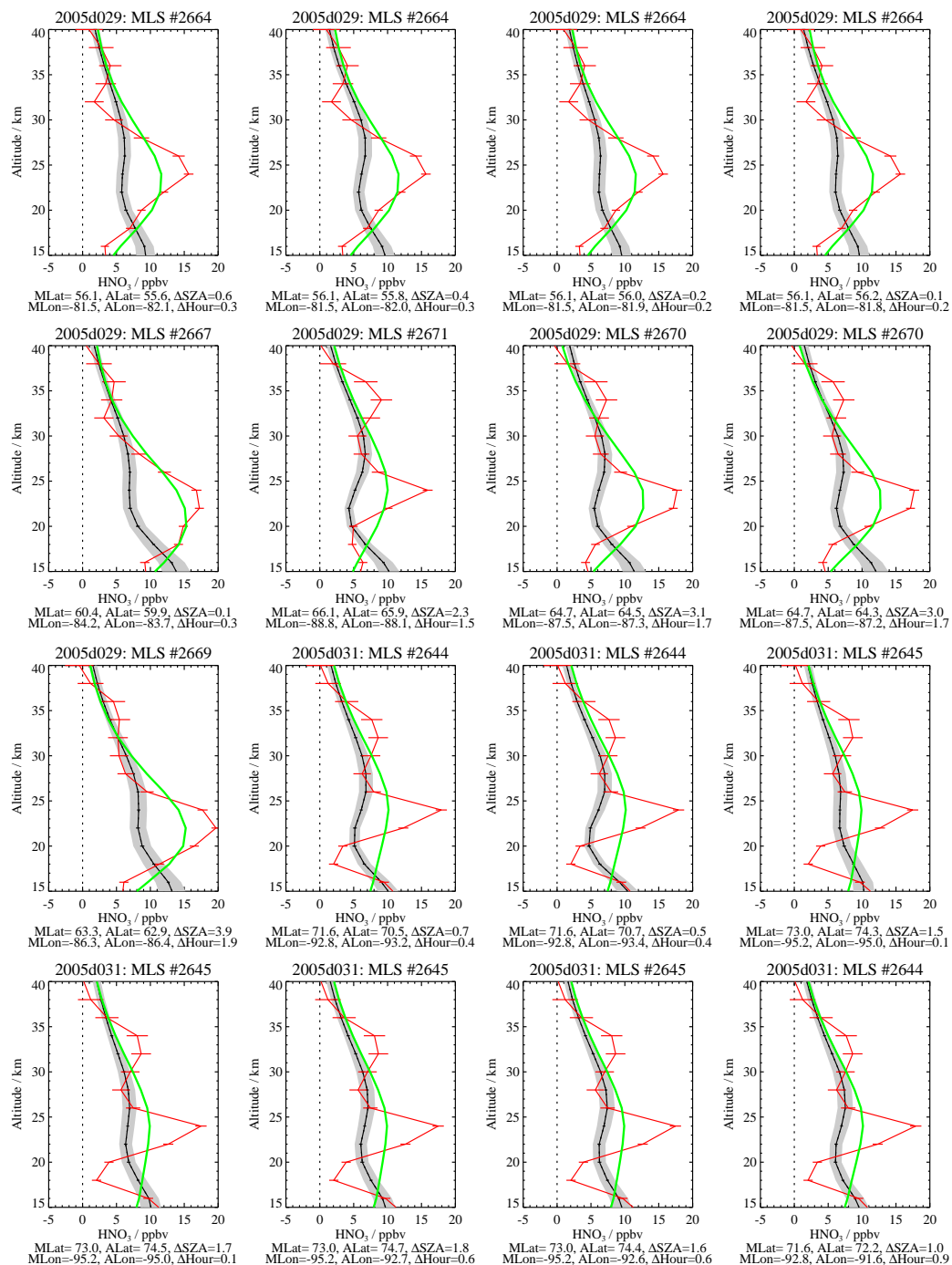
Data through 2005d254

580 K



- ❖ This plot is similar to that shown on the previous slide, but for 580 K ( $\sim 32$  hPa, 22 km).
- ❖ In terms of the latitudinal distribution of  $\text{HNO}_3$  and its seasonal evolution, agreement with the UARS MLS climatology is also very good at this level.
- ❖ However, the EOS MLS abundances are significantly higher than the climatological values in all latitude bands, especially at the higher latitudes in the fall and early winter.
- ❖ This suggests a high bias in the EOS MLS  $\text{HNO}_3$  measurements that is most pronounced when  $\text{HNO}_3$  is enhanced in the winter polar vortex.

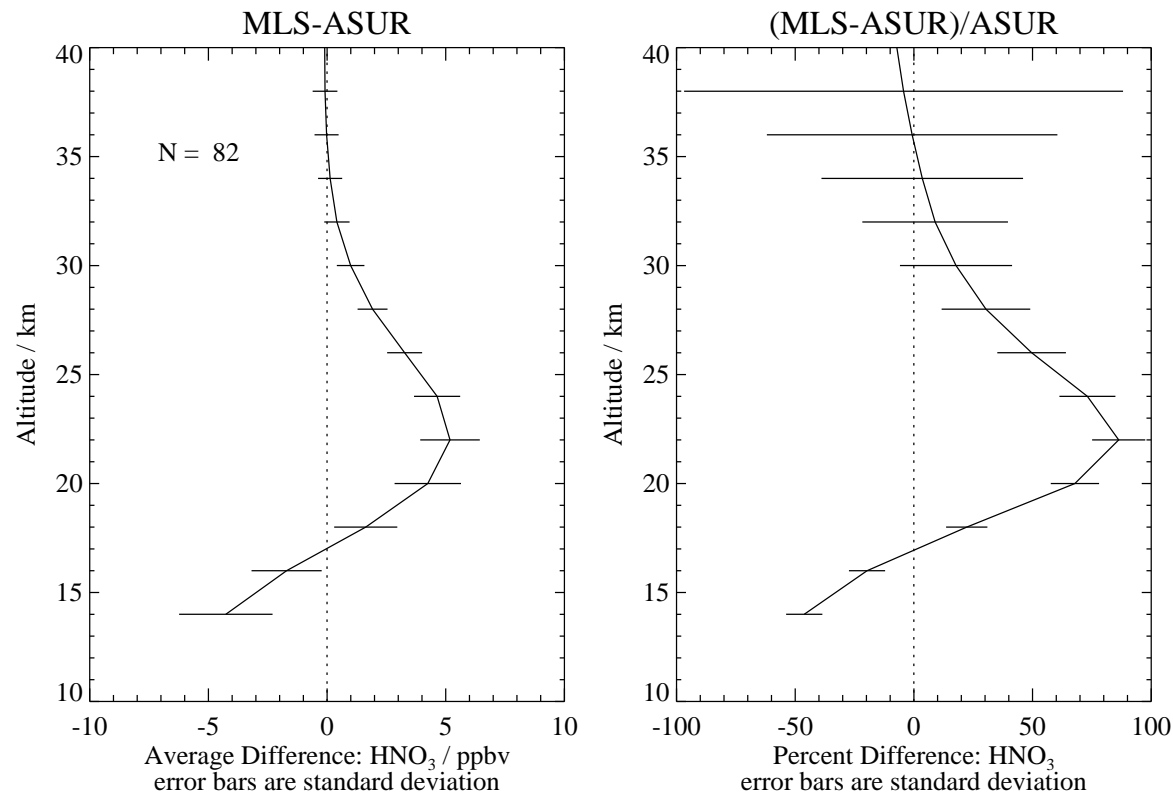
# Comparisons with ASUR: representative individual profiles



**ASUR** with estimated precision (error bars) and accuracy (grey shading)  
**MLS** with estimated precision  
**MLS** multiplied by ASUR averaging kernels

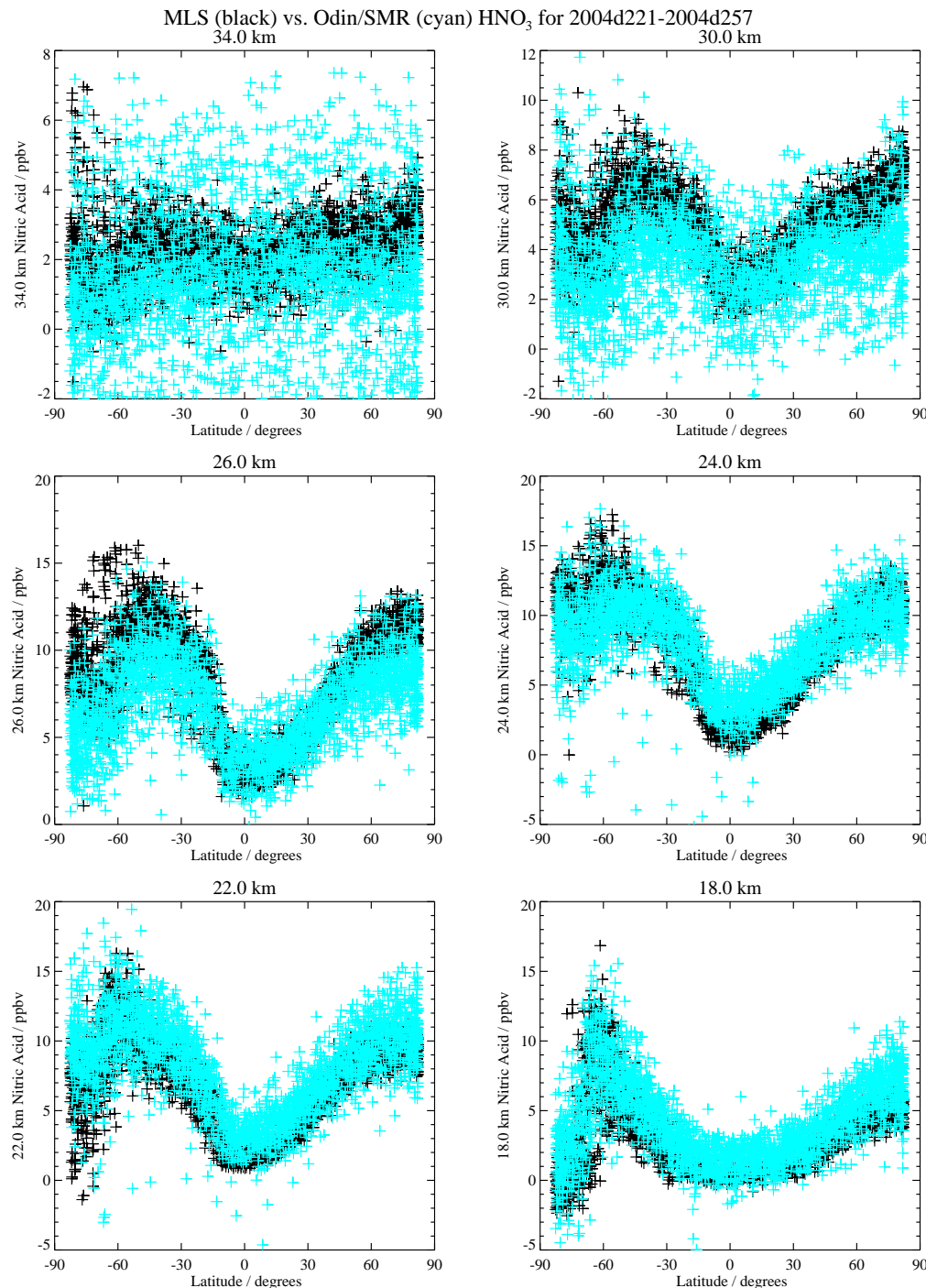
- ❖ The Airborne Submillimeter Radiometer (ASUR) flown on the DC-8 during PAVE (January/February 2005) measures  $\text{HNO}_3$  using a rotational band around 607 GHz from 14 to 40 km with 5–10 km vertical resolution and  $\sim 15\%$  accuracy.
- ❖ Several of the PAVE flights underflew the MLS track.
- ❖ Coincidence criteria:  $\pm 2^\circ$  latitude,  $\pm 4^\circ$  longitude,  $\pm 2$  hours.
- ❖ Many of the MLS profiles indicate  $\text{HNO}_3$  depletion around 18 km, most likely due to sequestration in PSCs.
- ❖ None of the ASUR  $\text{HNO}_3$  profiles have a peak near 20–25 km; in fact, most show a depression in that region.
- ❖ In contrast, all of the MLS profiles, even when smoothed with the ASUR averaging kernels, do show such a peak.

## Comparisons with ASUR: summary



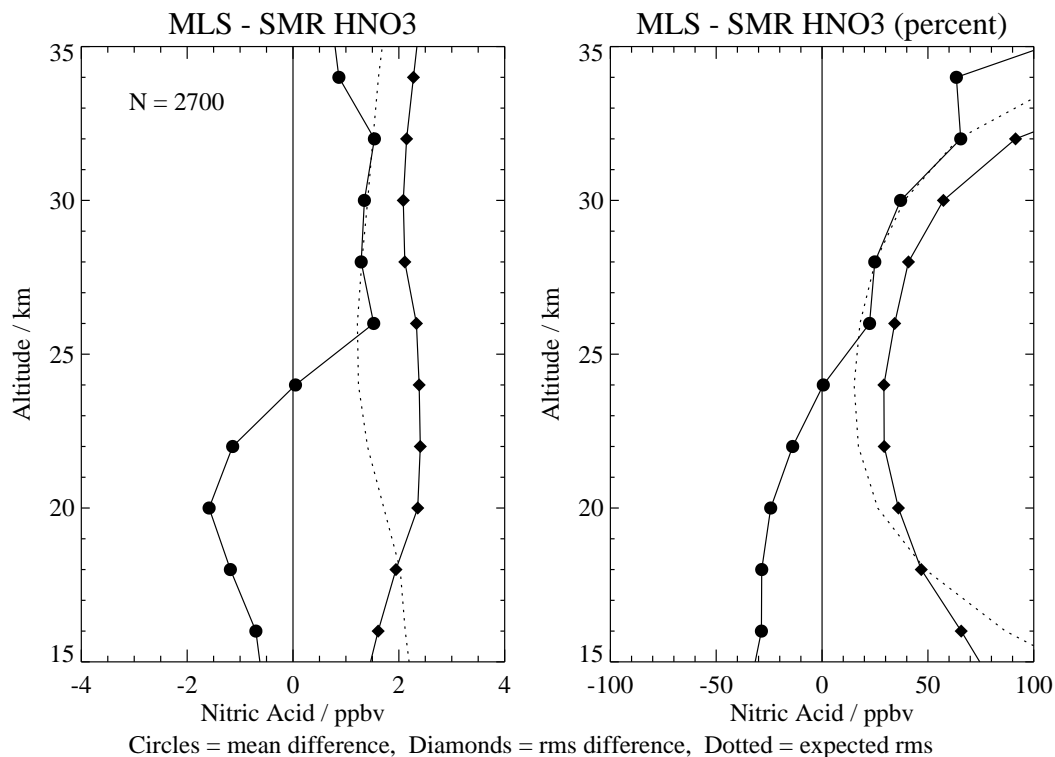
- ❖ Average differences between the MLS profiles multiplied by the ASUR averaging kernels and the ASUR profiles are small ( $< 1.0$  ppbv, 10–20%) above 30 km.
- ❖ However, average differences increase to as much as 5.0 ppbv at 20–25 km because the ASUR HNO<sub>3</sub> data exhibit no peak in the profile in this region at all.
- ❖ The ASUR team is aware of this apparent discrepancy and further investigations are planned.

# Comparisons with Odin/SMR: scatter plots



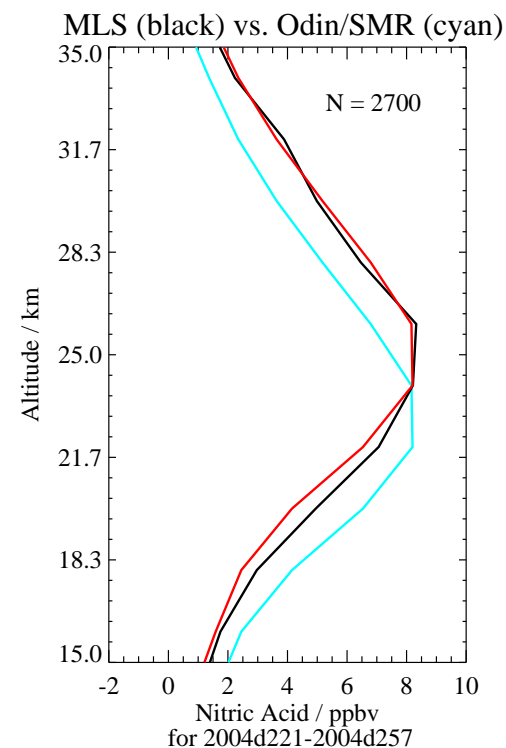
- ❖ The submillimeter radiometer (SMR) was launched on Odin in February 2001.
- ❖ SMR measures  $\text{HNO}_3$  at 545 GHz from 18 to 35 km with 1.5–2 km vertical resolution.
- ❖ Here we show “Chalmers-v2.0” data; “Chalmers-v1.2” data had better than 1.5 ppbv single-scan precision and an estimated systematic error of 0.5–0.7 ppbv for 20–25 km, better than 0.5 ppbv above [Urban et al., JGR 110, 2005].
- ❖ **MLS** and **SMR** data are scattered vs. latitude for all coincident profiles over the interval 8 August to 13 September 2004.
- ❖ Coincidence criteria:  $\pm 1^\circ$  latitude,  $\pm 8^\circ$  longitude,  $\pm 12$  hours
- ❖ Agreement is generally good, although MLS  $\text{HNO}_3$  mixing ratios are typically larger than SMR values above 24 km and smaller below.
- ❖ SMR measurements appear to be slightly noisier at most latitudes and altitudes.

# Comparisons with Odin/SMR: summary

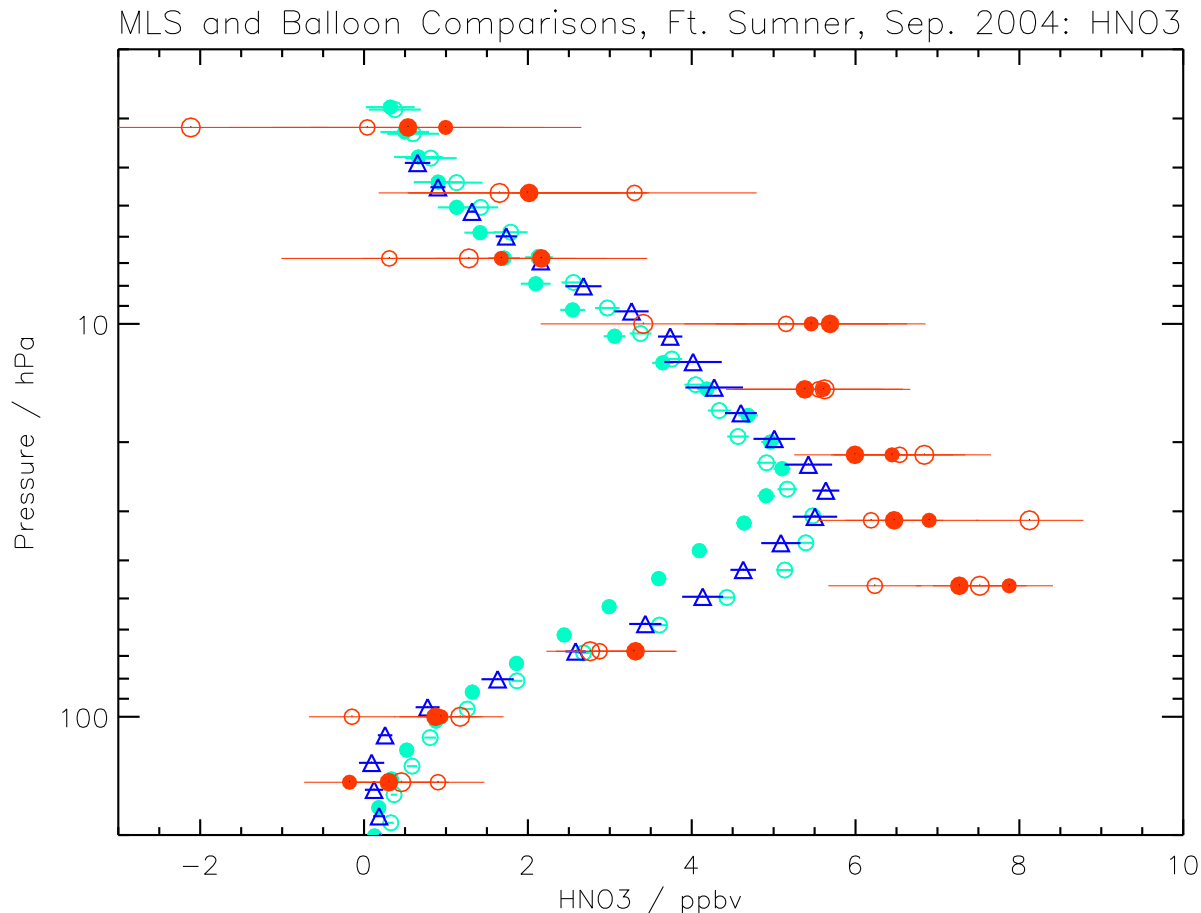


- ❖ Average differences between MLS and SMR HNO<sub>3</sub> are within 1.5 ppbv throughout the vertical range, corresponding to better than 30% agreement except at the topmost levels.
- ❖ MLS and SMR HNO<sub>3</sub> values match almost exactly at 24 km, but MLS HNO<sub>3</sub> is larger above and smaller below this level.
- ❖ This is also clearly seen in comparing the average SMR and MLS HNO<sub>3</sub> vertical profiles.

- ❖ This apparent shift suggests the possibility of a pointing offset between the two instruments.
- ❖ Shifting the SMR profile up uniformly by 2 km (red line) produces excellent agreement with MLS.
- ❖ However, none of the other products such as ClO, N<sub>2</sub>O, or O<sub>3</sub> show similar evidence of a pointing issue between the two instruments.
- ❖ Interestingly, the peak HNO<sub>3</sub> mixing ratios observed by SMR match those of MLS extremely well, in contrast to the results from infrared instruments.



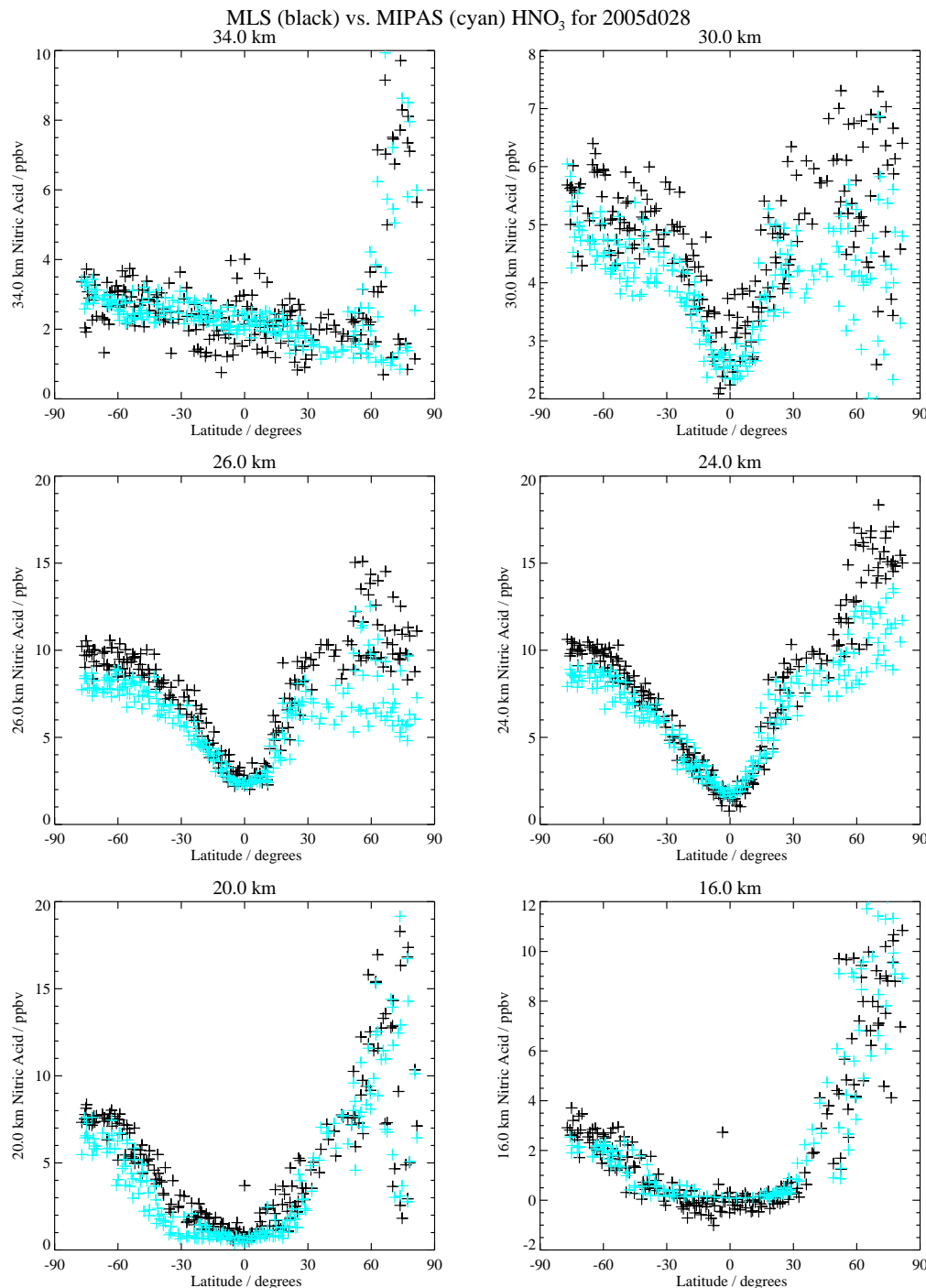
# Comparisons with balloon measurements



- ◆ Measurements were made near Aura overpasses during a balloon campaign from Ft. Sumner, NM on 23/24 September 2004.
- ◆ Remote HNO<sub>3</sub> measurements are available from:
  - ◆ the Smithsonian Astrophysical Observatory far-infrared spectrometer **FIRS-2** for both day (open circles) and night (closed circles) using the mid-IR (350–700 cm<sup>-1</sup>) channel.
  - ◆ the JPL **MkIV** solar occultation Fourier transform infrared spectrometer (sunset)

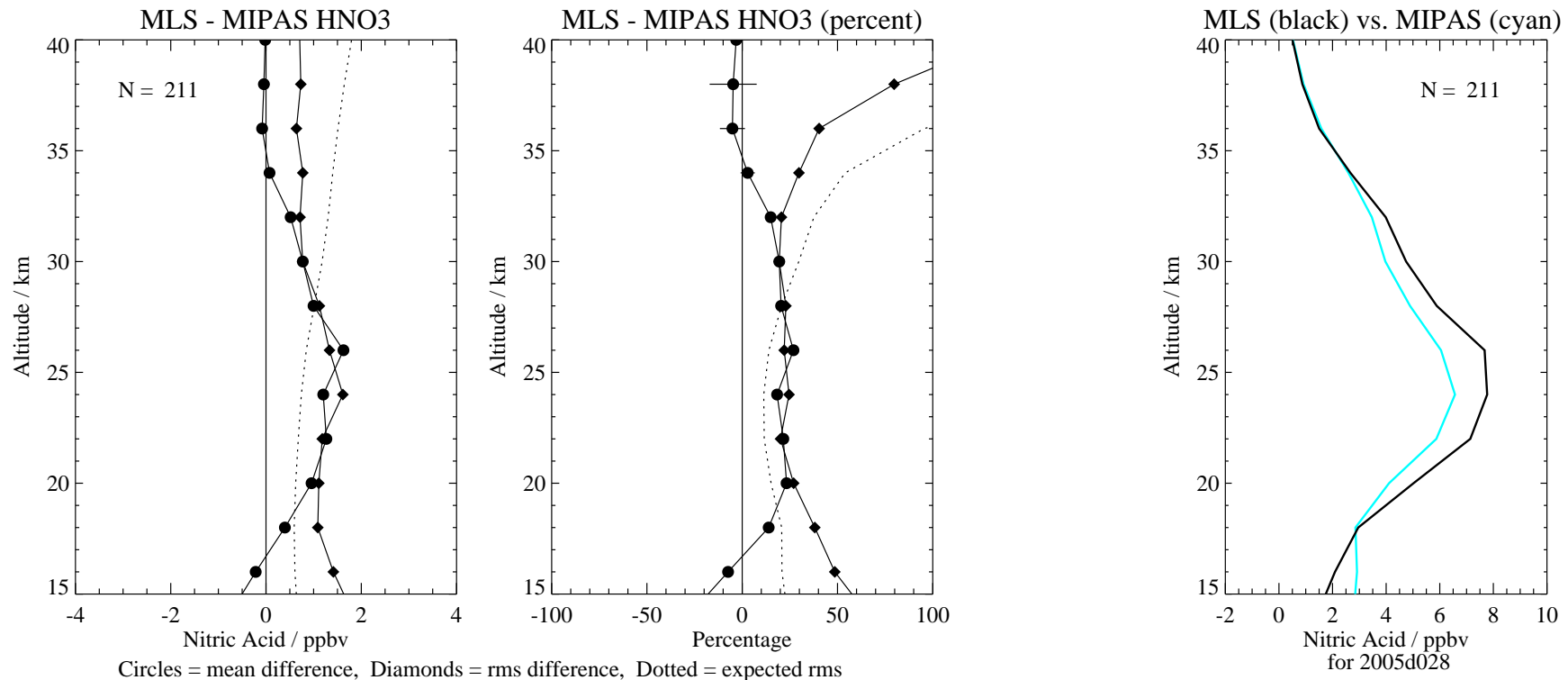
- ◆ The two closest day (open circles) and night (closed circles) **MLS** HNO<sub>3</sub> profiles are compared, with the larger symbol representing the profile closer to the corresponding **FIRS-2** profile.
- ◆ **MLS** HNO<sub>3</sub> mixing ratios can exceed those measured by the balloon instruments by as much as 3 ppbv at the levels around the profile peak.
- ◆ The magnitude of this discrepancy is well outside the combined error bars in some cases.
- ◆ Agreement is typically much better away from the peak at the top and bottom of the vertical range.
- ◆ This plot is included in Froidevaux et al., IEEE, submitted, 2005.

# Comparisons with MIPAS: scatter plots



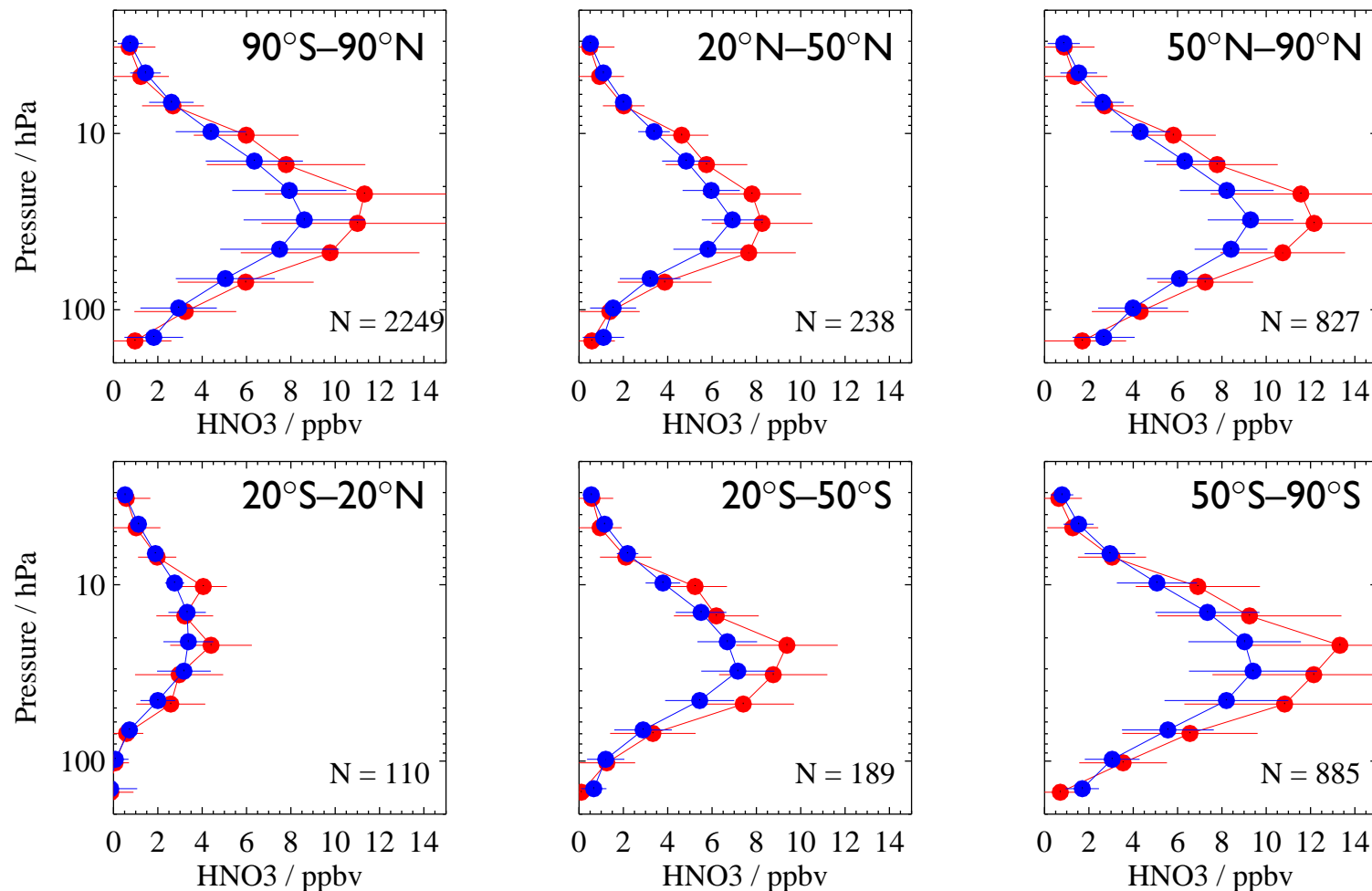
- ❖ The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) was launched on ENVISAT in March 2002.
- ❖ MIPAS measures  $\text{HNO}_3$  from bands near  $1.5 \mu\text{m}$  ( $870 \text{ cm}^{-1}$ ).
- ❖ Here we show “Preliminary Oxford Retrievals” from Claire Waymark at Oxford University (**not** the operational retrievals produced by ESA).
- ❖ **MLS** and **MIPAS** data are scattered vs. latitude for all coincident profiles from three orbits on 28 January 2005.
- ❖ Coincidence criteria:  $\pm 1^\circ$  latitude,  $\pm 8^\circ$  longitude,  $\pm 12$  hours
- ❖ Agreement is generally good, although MLS  $\text{HNO}_3$  mixing ratios are typically larger than MIPAS values, particularly at middle/high latitudes near the profile peak.
- ❖ The interesting feature seen at northern high latitudes at 34 km in both datasets may be  $\text{HNO}_3$  enhancement associated with a solar proton event earlier in the month; similar enhancement has been documented previously in MIPAS  $\text{HNO}_3$  [Orsolini et al., GRL 32, 2005].

# Comparisons with MIPAS: summary



- ❖ Average differences between MLS and MIPAS HNO<sub>3</sub> are within 1.5 ppbv throughout the vertical range, corresponding to ~20% agreement.
- ❖ As with the balloon measurements, very good agreement is found at the top and bottom of the profile, whereas MLS HNO<sub>3</sub> exceeds that from MIPAS at the levels surrounding the profile peak.
- ❖ The average disagreement with MIPAS is not as large as that seen in the comparisons of individual profiles with the balloon measurements.

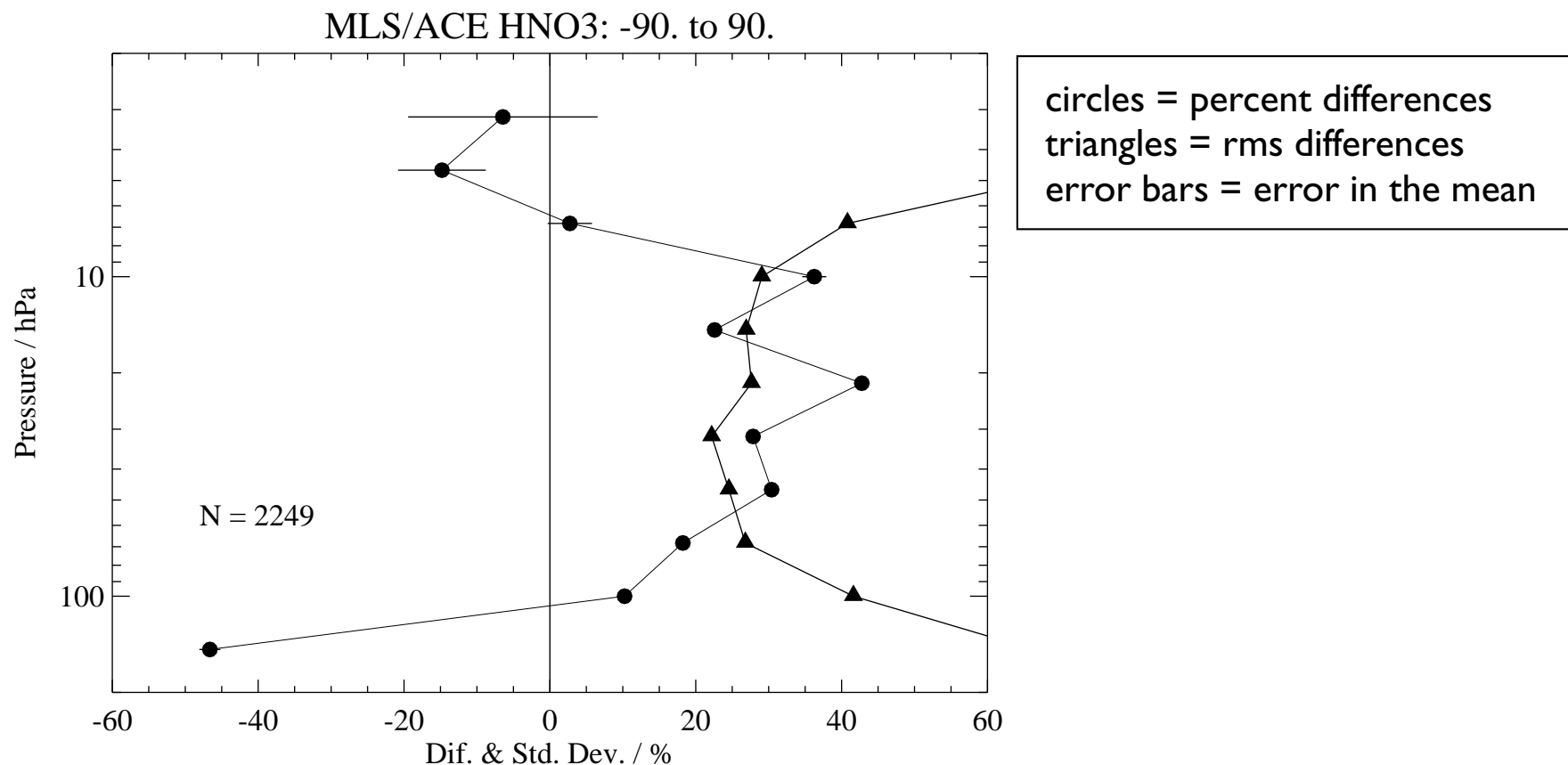
## Comparisons with ACE: latitude band averages



Adapted from Froidevaux et al., IEEE, submitted, 2005

- ❖ The Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS), launched on SCISAT in August 2003, makes measurements by solar occultation in the infrared (2–13  $\mu\text{m}$ ) with  $\sim 4$  km vertical resolution.
- ❖ Here we compare **MLS** HNO<sub>3</sub> with **ACE** v2.2 data over the interval 8 August 2004 to 10 August 2005, averaged in various latitude bands.
- ❖ **MLS** HNO<sub>3</sub> mixing ratios are high relative to **ACE** by 2–3 ppbv at the levels surrounding the profile peak at middle and high latitudes.

## Comparisons with ACE: summary



- ❖ Global mean statistics are shown here; results for all latitude bands are similar.
- ❖ ACE and MLS HNO<sub>3</sub> typically agree within ~10–20% near the top and bottom of the profile.
- ❖ MLS HNO<sub>3</sub> abundances are higher than those measured by ACE by ~20–40% at the levels surrounding the profile peak.
- ❖ Despite this apparent offset near the profile peak, however, comparisons of nearly-coincident individual measurements (not shown here) indicate very good agreement in capturing the overall shapes of the HNO<sub>3</sub> profiles and tracking variations in them (e.g., inside vs. outside the vortex, etc).

## Summary and future work

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- ❖ The standard product for version 1.5 HNO<sub>3</sub> is taken from the 240 GHz retrieval at and below 10 hPa and from the 190 GHz retrieval at and above 6.8 hPa.

**Useful range:** 147–3.2 hPa

**Vertical resolution:** 3.5–4.5 km

**Horizontal resolution:** ~300–400 km along-track, ~10 km cross-track; adjacent profiles separated by 1.5° (165 km)

**Precision:** ~1 ppbv throughout the vertical range

**Artifacts:** Based on comparisons with nearly-coincident satellite and balloon measurements, and a climatology of stratospheric HNO<sub>3</sub> based on 9 years of UARS MLS data, the MLS v1.5 HNO<sub>3</sub> retrievals appear to be biased high by about 3 ppbv (~30%) near the profile peak; because the MLS measurements agree well with those from Odin/SMR, and because previous comparisons between UARS MLS and GBMS data also indicated higher mixing ratios relative to infrared measurements, the extent to which this discrepancy may arise from uncertainties in either the infrared or the microwave spectroscopy is under investigation.

**Consistency checks:** The latitudinal distribution and seasonal variations match those measured by UARS MLS and also show excellent correspondence with MLS N<sub>2</sub>O and GEOS-4 PV.

**Accuracy:** MLS HNO<sub>3</sub> agrees with balloon and satellite measurements to within ~30%, with agreement slightly better at the top and bottom of the profile but worse around the peak.

- ❖ Priorities for Version 2 MLS HNO<sub>3</sub> data:
  - ❖ Understand and mitigate (if possible) the apparent large positive bias in HNO<sub>3</sub> abundances at the levels surrounding the profile peak.
  - ❖ Reduce oscillations in the HNO<sub>3</sub> vertical profile.
  - ❖ Attempt to improve the retrievals at 215 hPa.